AN EVALUATION OF THE BRIDGE SAFETY INDEX IN TEXAS

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CHAPTER I

INTRODUCTION

An unsafe narrow bridge is one that contributes to property damage, personal injury, or fatal accidents. The definition of what constitutes a hazardous narrow bridge and what are the specific bridge features that contribute most to making it hazardous are difficult to determine, primarily because of the lack of the documentation of factors that affect accidents at a narrow bridge site. Factors suggested in related studies include the bridge geometry, bridge structure, geometry of the approaching roadway, traffic volume, vehicle mix, driver error, and others. The technology exists for ameliorating bridge accident problems by constructing safer highways, bridges, and control and warning equipment. Because control and warning methods are passive measures, engineers prefer to improve active measures such as bridge geometry or structures or highway geometry to reduce accident rates or to reduce their severity. For instance, recent improvements in bridge rails are intended not only to prevent penetration by small and large size vehicles but also to provide safe redirection for such vehicles. Therefore, a subjective evaluation of bridge safety by engineers would be expected to emphasize these factors.

The Bridge Safety Index (BSI), which is such an approach to the evaluation of bridge safety, was developed by the Texas Transportation Institute. (1)* On the basis of data collected and the experience of the re-

*Numbers in parentheses refer to the corresponding item in the list of references.

searchers, they assigned weights to ten factors which were considered to contribute to bridge hazards, and the Bridge Safety Index was defined as the sum of these ten individual bridge site rating factors. Although the first attempt at such a definition was successful, some problems exist in the current Bridge Safety Index. For instance, it would be interesting to determine whether the weights on each of the ten factors can be found by more objective means. If it can be done, it would almost certainly show that each of the ten factors would have a different weight in determining the BSI. The Texas Transportation Institute undertook a study of narrow bridges to see if the Bridge Safety Index could be improved.

The purposes of this study are as follows:

1. Re-establish a Bridge Safety Index based on discriminant analysis,
2. Appraise the weights on the selected factors which would have a high degree of contribution to accident rates, and
3. Identify, using the new Bridge Safety Index, the potentially hazardous bridge.

The Statistical Analysis System (SAS), a package of computerized statistical procedures, is used to perform the majority of this study, and data utilized for analysis is taken from existing files of 78 bridge sites within Texas.

CHAPTER II

PREVIOUS STUDY

The Texas Transportation Institute conducted a comprehensive narrow bridge safety program, including a method of determining a priority rating for the improvement of bridges having restricted width. The data collected at 25 bridge sites throughout the U. S. was surveyed for bridge and highway geometries, traffic speed, bridge structures, traffic volume, surrounding circumstances, and others. The Bridge Safety Index (BSI) was estimated in terms of ten factors which were considered to contribute to hazardous bridge conditions. Weights were assigned to these ten factors, and the Bridge Safety Index was defined as the sum of these ten individual rating factors. As a result, the Bridge Safety Index (BSI) could be expressed as (1)

$$BSI = F_1 + F_2 + F_3 + \ldots + F_{10} \quad \text{(1)}$$

where F_1 = clear bridge width,

F_2 = bridge lane width/approach lane width,

F_3 - guard rail and bridge rail structure,

F_4 = approach sight distance/85% approach speed,

F_5 = 100 + tangent distance to curve/curvature,

F_6 = grade continuity,

F_7 = shoulder reduction,

F_8 = volume/capacity ratio,

F_9 = traffic mix (primarily the percent trucks), and

F_{10} = distractions and roadside activities.

With the exception of F_1, which is determined from Figure 1, all other nine factors are evaluated by relying on Table 1. Also, the factors F_1, F_2, and F_3 are rated from 0 to 20, and the remaining seven factors are rated from 1 to 5. Thus, the most ideal bridge site conditions produced a BSI of 95 and a critically hazardous site had a value of 20.

The report also described a method of determining the priority in making improvements in narrow bridges by using the BSI to rate planned corrective treatments. Accordingly, the priority index was defined as the ratio of the benefit to people that would be realized with a particular corrective measure divided by the total cost. A model for setting priorities presented by D. L. Ivey, et.al. was expressed as (1)

$$PI = \frac{(BSI_A - BSI_B) \times KADT}{C} \quad \text{.......................................}(2)$$

where PI = priority index,

BSI_A = Bridge Safety Index after treatment,

BSI_B = Bridge Safety Index before treatment,

KADT = average daily traffic, in 1000's, and

C = cost of the treatment or bridge hazard improvement.

During 1978 and 1979, a study to evaluate the BSI and the priority index was conducted by the Texas State Department of Highways and Public Transportation at 78 selected bridge sites within the State of Texas. Appendix I presents the results of each rating factor and of the BSI for each study bridge site. Also, the districts proposed a comprehensive safety program for each bridge site as summarized in Appendix II. However, a review of the recommendations for corrective treatments, and an

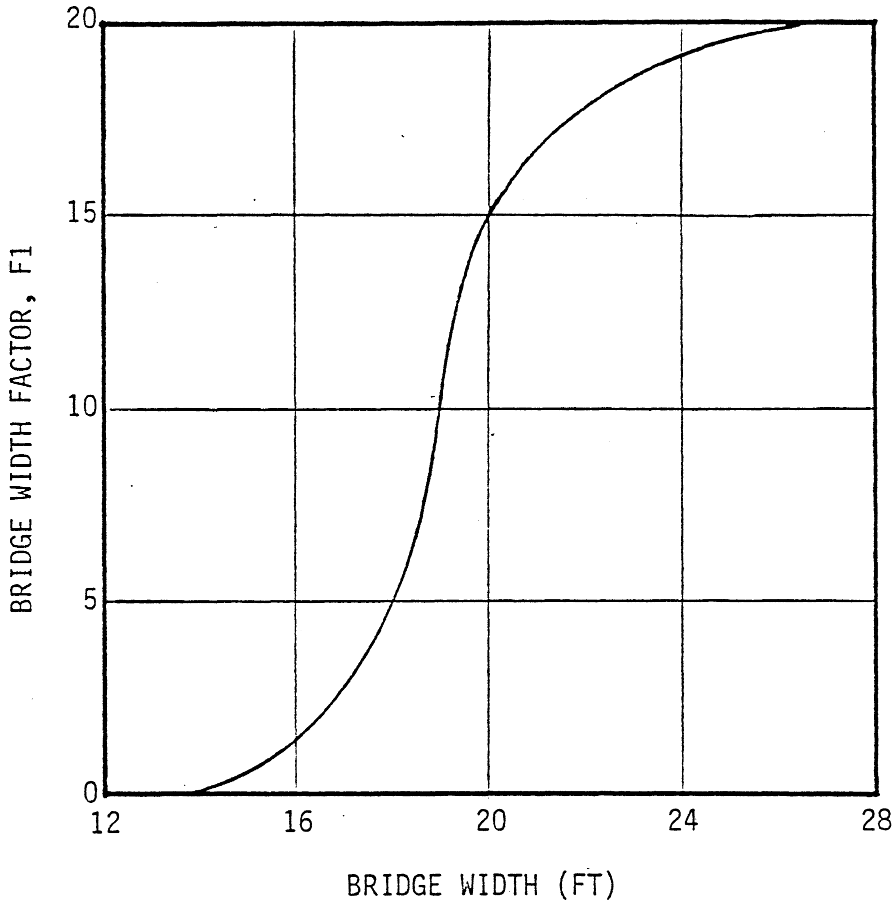

Fig. 1. Weighting of Bridge Width Factor (F1)

Table 1. Factors Used to Determine Bridge Safety Index

	Factor Rating for F2 and F3				
	0	5	10	15	20
F2	0.8	0.9	1.0	1.1	1.2
F3	Critical	Poor	Average	Fair	Excellent
	Factor Rating for F4 - F10				
	1	2	3	4	5
F4	5	7	9	11	14
F5	10	60	100	200	300
F6	10	8	6	4	2
F7	100	75	50	25	None
F8	0.5	0.4	0.3	0.1	0.05
F9	Wide Dis-continuities	Non-Uniform	Normal	Fairly Uniform	Uniform
F10	Continuous	Heavy	Moderate	Few	None

evaluation of the BSI and PI after treatment revealed that a problem existed in the definition of one or the other. For instance, a corrective treatment such as "Bringing and Maintaining Markings to High Level" can not be applied in a simple way to Table 1 to evaluate BSI after treatment. With no change in BSI due to the corrective treatment, the treatment would receive a zero priority index. The question immediately arises whether pavement markings affect bridge safety. Turner, in his dissertation (2), cited several publications which summarized how bridge safety was influenced by some corrective treatments. These included: (a) install delineators at bridge, (b) pavement edge marks at narrow bridge, (c) install or improve warning signs, and others. Because improvements a, b, and c can not be rated directly by the current definition of BSI, it is reasonable to add more factors to the definition.

CHAPTER III

RESEARCH APPROACH

The preceeding review revealed that there are some limitations in determining and applying to the Bridge Safety Index presented by D. L. Ivey, et.al. (1) For these reasons, it was desirable to develop by statistical means an equation for the BSI which contains all previous variables in addition to those that rate explicitly the improvements that were planned by the Texas SDHPT so that a new BSI and new PI can be estimated. By using statistical analysis, it is expected that better parameters for modeling bridge safety could be found, and an evaluation of the significance of the individual variables in the BSI could be made. This requires the addition of more variables upon which the BSI may depend and by using statistical techniques develop a new equation for evaluating the Bridge Safety Index. Details of this development are described in the following section.

New Factors, F_{11}, F_{12}

In order to avoid complicated variables and considering the improvements in hazardous bridge conditions that were recommended by 15 districts, only two factors, F_{11} and F_{12} were added as variables in this study of the BSI. The F_{11} factor, paint marking, is defined as the combination of centerline, no passing zone stripes, edge lines, and diagonal lines on the shoulder of the pavement. The F_{12} factor, warning signs or reflectors, is defined in terms of narrow bridge signs, speed signs, reflectors on the bridge, or black-white panels on the bridge ends. It is considered that these factors are effective in reducing the lateral movement of the vehicle, changing the vision of the driver, and controlling speed. These are also expected to contribute to a reduction in the probability of accidents, and thus should be included in the Bridge Safety Index.

Table 2 shows a way of determining the factor F_{11} in the field which is separated into three main items, i.e. centerline and no passing zone stripes, edge lines, and diagonal lines. The nomogram shown as Figure 2, like the weighting factor F_3, is used to convert from the word descriptions to a quantitative value for rating the F_{11} factor. Table 3 shows a way for evaluating the F_{12} factor which contains the narrow bridge signs, speed signs, reflectors, and black-white panels, or other markers. Engineering judgement will be used to convert the observed estimation into one of the descriptive terms. It should be noted that the rating of these two factors are assigned values from 1 to 5 in this study.

Data Source

The data used for developing a new Bridge Safety Index were taken from data collected in 1978 and 1979 by the Texas Transportation Institute at the 78 bridge sites where corrective treatments were recommended in the 15 districts for the State of Texas. An initial evaluation to the factors of each bridge site was based on the field method (3) in which F_1, F_2, and F_3 are rated from 0 to 20. The other factors are assigned ratings from 1 to 5 as shown in Appendix I. For the purpose of statistical analysis to obtain the significance in each factor, the

Table 2. Evaluation of F11 Factor

F11 Painting Marking __________

	Adequate	Marginal	Inadequate
Centerline or No Passing Zone Stripes		√	
Edge Line	√		
Diagonal Line		√	

Table 3. Evaluation of F12 Factor

F12 Warning Sign or Reflectors __________

Excellent	5
Fair	4
Average	3
Poor	2
None	1

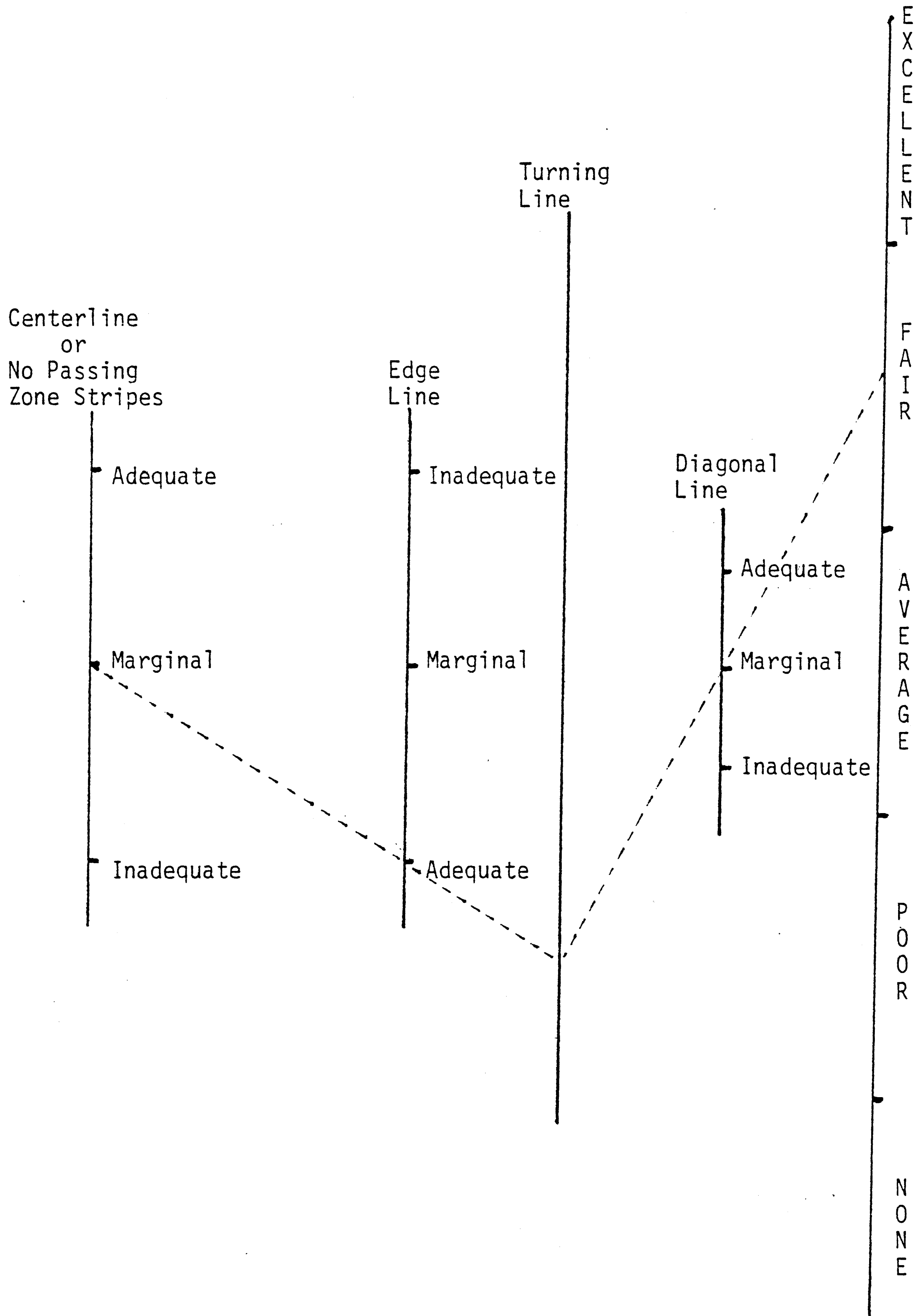

Fig. 2. Nomogram Used to Determine F_{11}

ratings with respect to each factor are constrained to have a maximum value of 5, i.e. all ratings are based on same unit, and the relative weights will be determined by statistical analysis. Because of this, the factors F_1, F_2, and F_3 are corrected appropriately by dividing by 4, thus resulting in the same scale as the rest of the factors. In addition, the ratings of F_{11} and F_{12} are developed from the available slides of each selected bridge and from recommendations by each district. The final set of corrected data is shown in Table 4. These were the input data for the statistical analysis in this study.

Discriminant Analysis

If data are collected on several variables from two or more groups of subjects and it is desired to describe the ways in which the groups differ on these variables, an approach to achieve this differentiation is called a discriminant function analysis. Its objectives involve (a) maximizing the discrimination among the groups in terms of their means by a linear combination of the variables, and (b) establishing the boundaries for the assignment of new individuals into one of the groups (4).

A general linear discriminant equation is expressed as

$$Z = a_1x_1 + a_2x_2 + \ldots.. a_nx_n \qquad (3)$$

where Z = discriminant score,

$a_1, a_2, a_3, \ldots.. a_n$ = coefficients, and

$x_1, x_2, x_3, \ldots.. x_n$ = independent variables.

Table 4. Modified Data of 78 Bridges

Bridge Site	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12
2C--Tarrant 220	5	5	5	5	5	1	1	4	3	3	1	2
2D--Wise 249	5	3.75	2.50	5	5	5	1	5	2	5	3	2
2E--Erath 73	5	5	1.25	5	5	2	1	4	4	2	3	3
2F--Erath 73	4.5	2.50	0.00	4	4	3	1	5	3	4	3	3
2G--Hood 112	5	5	2.50	5	5	5	1	4	2	2	3	2
2H--Erath 73	4.5	2.50	3.75	5	5	5	1	5	4	4	3	3
9A--Bell 14	5	1.25	1.25	5	5	1	2	4	3	4	3	3
9F--Bell 14	5	1.25	2.50	5	5	1	3	5	2	3	1	2
9G--Bell 14	5	3.75	0.00	3	1	5	1	2	1	4	1	2
10D--Henderson 108	5	2.50	1.25	5	5	5	2	4	2	2	1	2
10F--Anderson 001	4.25	1.25	0.00	5	5	2	5	5	4	4	1	2
10G--Gregg 93	5	1.25	1.25	5	5	5	5	4	5	4	3	2
10H--Van Zandt 234	2.5	2.50	0.00	5	3	1	5	5	4	4	1	2
10I--Anderson 001	5	3.75	2.50	5	5	5	1	4	1	1	1	2
10C--Henderson 108	5	2.50	1.25	5	5	5	2	4	2	2	1	2
11C--Trinity 228	5	2.50	1.25	5	4	5	1	4	3	3	1	1
11D--Trinity 228	5	2.50	1.25	5	5	5	1	4	3	3	2	2
11E--Houston 114	5	3.75	1.25	5	5	5	5	5	5	5	1	2
11F--San Aug 203	5	2.50	1.25	5	5	5	2	5	4	4	1	1
12A--Brazoria 20	5	3.75	1.25	5	1	5	1	4	4	4	3	2
12G--Harris 102	5	2.50	0.00	5	5	1	1	2	2	1	1	3
12I--Brazoria 20	5	3.75	1.25	5	5	1	1	4	4	3	1	3
12J--Brazoria 20	5	1.25	0.00	5	5	5	5	4	3	3	1	2
12K--Harris 102	5	1.25	0.00	5	5	5	5	4	4	4	3	2

Table 4. (Continued)

Bridge Site	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12
12L--Montgmry 170	5	2.50	1.25	5	5	5	5	4	2	2	3	2
13A--Calhoun 29	5	2.50	1.25	5	5	5	2	5	3	5	4	1
13B--Colorado 45	5	2.50	0.00	5	1	4	1	4	2	2	2	3
13F--Dewitt 62	5	2.50	5	5	5	5	1	4	3	1	1	2
13D--Fayette 76	5	2.50	1.25	5	3	4	1	4	3	2	1	2
13E--Gonzales 90	5	2.50	2.50	5	5	5	1	4	4	1	1	2
13C--Dewitt 62	5	2.50	3.75	5	4	5	1	4	3	1	2	2
14A--Bastrop 11	5	1.25	1.25	5	2	3	1	4	5	2	1	3
14C--Llano 150	5	2.50	1.25	5	5	3	1	5	3	1	2	1
14E--Bastrop 11	4.5	1.25	1.25	5	5	3	5	5	5	5	1	2
14F--Hays 106	5	2.50	1.25	1	1	1	5	5	3	1	1	3
14D--Wmson 246	5	5	2.50	5	5	3	5	5	5	5	1	2
14H--Wmson 246	5	5	2.50	5	5	4	1	5	4	4	1	2
14I--Wmson 246	5	5	5	5	2	5	1	4	4	3	1	2
16D--Refugio 196	5	2.50	3.75	5	3	3	3	4	2	4	3	2
16E--Refugio 196	5	2.50	5	5	5	5	3	4	2	4	4	2
16F--Sanpatricio 205	3.75	2.50	3.75	5	5	5	1	5	3	4	2	3
16G--Sanpatricio 205	3.75	2.50	3.75	5	5	5	1	5	3	4	2	3
18B--Denton 61	5	2.50	3.75	5	5	5	1	4	2	2	1	2
18C--Kaufman 130	5	3.75	2.50	5	1	4	1	4	2	3	3	3
18D--Navarro 175	5	5	0.00	5	5	5	1	5	5	5	1	3
20B--Hardin 101	5	2.50	1.25	5	5	5	2	4	2	4	2	2
20F--Jasper 122	5	2.50	1.25	5	5	5	2	4	2	4	2	2
20H--Liberty 146	3.75	5	0.00	5	5	5	1	5	2	4	2	2

Table 4. (Continued)

Bridge Site	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12
20I--Hardin 101	5	3.75	1.25	5	5	5	1	4	3	3	2	2
3B--Wichita 243	4.5	1.25	0.00	5	4	5	1	5	4	3	1	5
3C--Wilbarger 244	4.5	1.25	2.50	5	3	4	1	5	2	3	1	4
3D--Wilbarger 244	4.5	1.25	0.00	5	3	4	1	5	2	3	1	3
3E--Wilbarger 244	4.5	1.25	0.00	5	5	5	1	5	2	3	1	3
3F--Young 252	4.5	0.00	0.00	4	5	3	1	5	2	4	1	5
3G--Young 252	3.75	2.50	0.00	5	3	2	1	5	2	4	1	2
3H--Montaque 169	4.5	1.25	0.00	5	5	2	1	5	3	4	2	3
4A--Hartley 104	5	3.75	3.75	5	5	5	1	5	2	3	1	2
4B--Hemphill 107	5	5	2.50	5	1	5	1	5	3	4	1	2
4D--Oldham 180	5	2.50	2.50	5	1	2	1	5	2	4	1	2
4E--Oldham 180	5	3.75	1.25	5	4	3	1	5	2	4	1	2
4F--Randall 191	5	5	0.00	5	3	2	1	4	4	2	1	2
7A--Coke 41	5	2.50	2.50	5	5	4	2	5	3	4	3	1
7G--Tom Green 226	3.75	1.25	0.00	2	1	5	5	5	3	2	1	3
7H--Tom Green 226	5	3.75	2.50	4	3	5	1	3	4	2	1	1
7I--Tom Green 226	5	2.50	1.25	5	1	2	2	4	4	2	1	1
21A--Kenedy 66	5	2.50	1.25	5	5	4	4	4	2	4	2	3
21B--Duval 67	5	2.50	5	5	5	5	5	5	4	5	1	2
21D--Hidalgo 109	5	3.75	0.00	5	3	5	1	5	4	3	3	2
21G--Webb 240	5	2.50	1.25	4	1	2	1	4	3	2	1	2
21H--Zapata 253	5	3.75	2.50	5	5	4	1	5	3	4	4	2
21I--Zapata 253	5	3.75	2.50	5	5	4	1	4	3	2	3	2
22A--Kinney 136	5	1.25	2.50	5	5	4	3	5	4	3	3	2

Table 4. (Continued)

Bridge Site	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12
22B--Kinney 136	5	2.50	1.25	5	5	3	3	5	4	5	4	2
22C--Maverick 159	5	2.50	0.00	5	5	5	3	5	4	3	4	2
22D--Uvalde 232	5	3.75	0.00	5	5	4	1	5	5	4	1	2
22E--Val Verde 233	5	5	1.25	5	5	2	1	5	4	1	1	1
22F--Val Verde 233	5	3.75	1.25	5	1	4	1	5	4	2	2	1
22H--Zavala 254	5	3.75	0.00	5	5	5	1	5	4	4	1	2

The value of the a's in the discriminant equation are chosen so as to maximize the ratio of the variance of the means between groups to the variance within the groups, as defined in (5)

$$\left.\frac{\text{variance between means on Z}}{\text{variance within group on Z}}\right|_{\text{maximize}} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (4)$$

In the development of the discriminant function, a subprogram of Statistical Analysis System called "DISCRIM" is used in this study.

Discriminant Analysis Based on MBSI score

Before the "DISCRIM" procedure is used, it is required to assign all of the available bridges into two groups on some "a priori" basis, such as by defining each bridge as either "safe" or "hazardous," since it is assumed that only two groups exist. The problem arises as to how to define the bridges as "safe" or "hazardous." Initially, the criterion for this classfication was the assumption that all bridges with "a priori" MBSI (modified BSI from the original data) of 38.5 or above are "safe" bridges. The 38.5 figure was chosen because it lies between the two peaks as shown in Figure 3. A sequence of trial and error calculations is made, in which groups are assigned on the basis of an assumed boundary value of MBSI, and the probability of discriminating on that basis is calculated. The best boundary value of MBSI is the one that produces the highest probability of discrimination. By this means, a value of 38.75 was found to separate the two groups best. The final results are shown in Appendix III in which group "0" represents the assumed hazardous

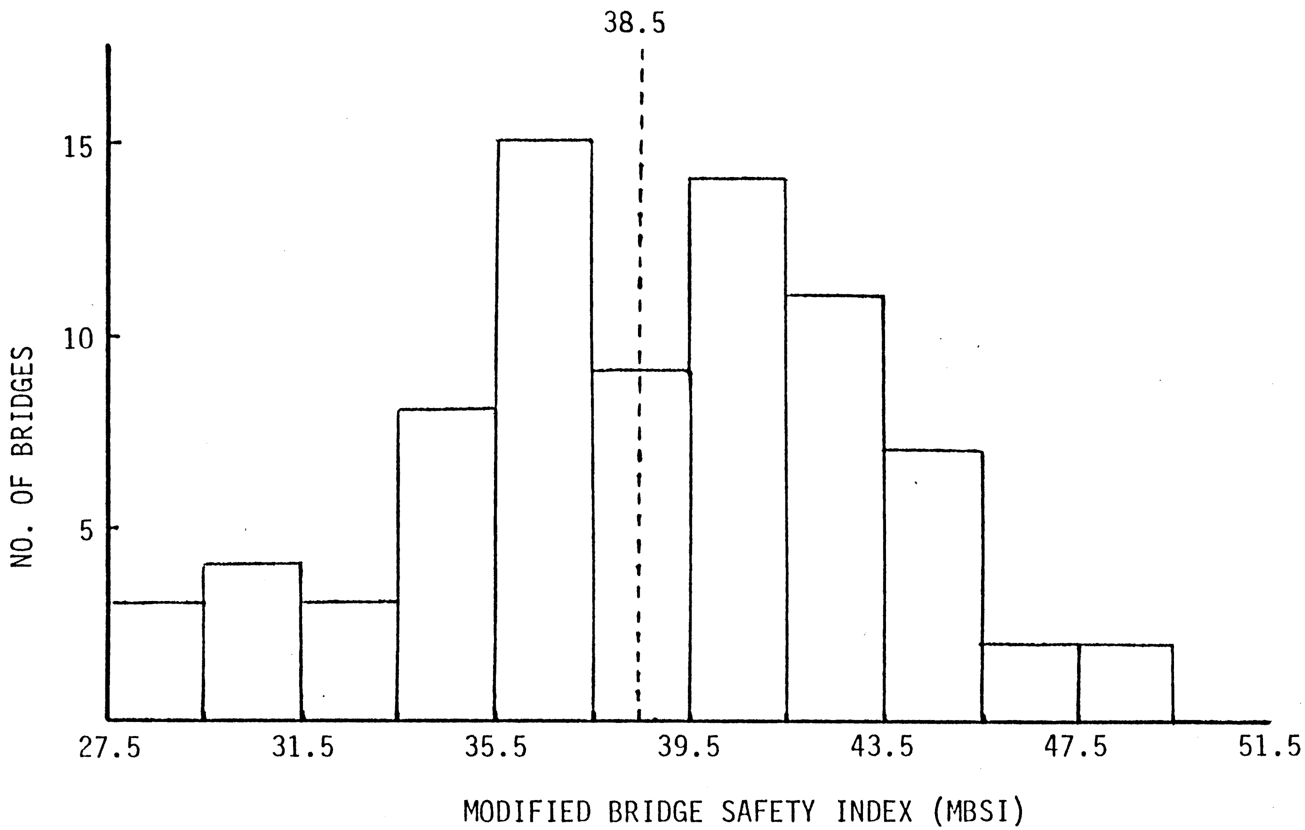

Fig. 3. Distribution of Modified Bridge Safety Index and Initial Boundary Chosen for Classification

bridges and group "1" represents the safe bridges. Table 5 summarizes the coefficients of the linear discrimination function based on the criterion stated above. The discriminant equation thus developed defines a new Bridge Safety Index (BSI) which can be expressed as

$$\begin{aligned} BSI = {} & 1.48F_1 + 2.19F_2 + 0.97F_3 + 0.47F_4 + 0.93F_5 + 1.33F_6 + \\ & 1.47F_7 + 0.23F_8 + 0.9F_9 + 1.75F_{10} + 1.78F_{11} + 0.72F_{12} \quad \ldots (5) \end{aligned}$$

The coefficients show the relative weight that is applied to each of the 12 factors. Thus, through discriminant analysis it has been found that all 12 factors have different significance in determining the MBSI. Determining the relative significance is one of the major objectives in this study. It is considered that Eq.(5), which was developed by discriminant analysis should be more a reasonable representation of a Bridge Safety Index than Eq.(1), which was developed subjectively by D. L. Ivey, et.al. This Eq.(5) will be used in a subsequent section of this report to determine a new priority index for bridge improvements.

Discriminant Analysis Based on Accident Rate

The criterion for classification into safe and hazardous groups that was used above was an "a priori" MBSI score, which is, in itself, subjective. In an attempt to use a more objective means of discriminating between the two groups, it is of interest to use the accident rate (No. of Accidents/Yr./1000 ADT) as a criterion to classify bridges into two groups since such a criterion should be less subjective than that of BSI score. Generally speaking, it is assumed that the higher the BSI is,

Table 5. Coefficients Used with Discriminant Function Based on MBSI Score

Variable	Coefficient
F1	1.48
F2	2.19
F3	0.97
F4	0.47
F5	0.93
F6	1.33
F7	1.43
F8	0.23
F9	0.90
F10	1.75
F11	1.78
F12	1.72

the lower the accident rates should be. However, a question arises as to whether all of the selected factors have a relationship with accident rates. If the selected factors are strongly correlated with accident rates, the results of discriminating a safe from a hazardous bridge using such a criterion with discriminant analysis should give a more reliable Bridge Safety Index. For the moment, it is assumed that a relationship exists between the selected factors and accident rates. The available accident data for each selected bridge site from 1974 to 1979 was gathered from the Texas State Department of Highways and Public Transportation where it was available in their computer files on accidents. Appendix IV summarizes the accident data for each bridge site that was derived from these files.

The problem also arises in defining the boundary of the accident rates so as to assign bridge sites into safe or hazardous classes. Trial and error is used to determine this boundary value of accident rate, as was done previously with the MBSI. The distribution of accident rate data on these bridges is shown in Fig. 4. Unfortunately, the groups are not well discriminated even though several attempts were made. The results are shown as Appendix V. In this attempt, based on a boundary accident rate of 0.3175, 38 bridges are placed into group "0" in which there are 12 bridges misclassified (31.58%); 40 bridges are classified into group "1" in which there are 9 bridges misclassified (22.5%). Table 6 summarizes the coefficients to be used with the linear discriminant function for ABSI (or Accident-related Bridge Safety Index). The equation of ABSI based on the accident rate criterion can be expressed as

$$\begin{aligned} ABSI = {} & 1.92F_1 + 0.07F_2 - 0.17F_3 - 0.50F_4 + 0.28F_5 + 0.0004F_6 + \\ & 0.02F_7 + 0.02F_8 - 0.13F_9 + 0.49F_{10} + 0.26F_{11} - 0.48F_{12} \quad ..(6) \end{aligned}$$

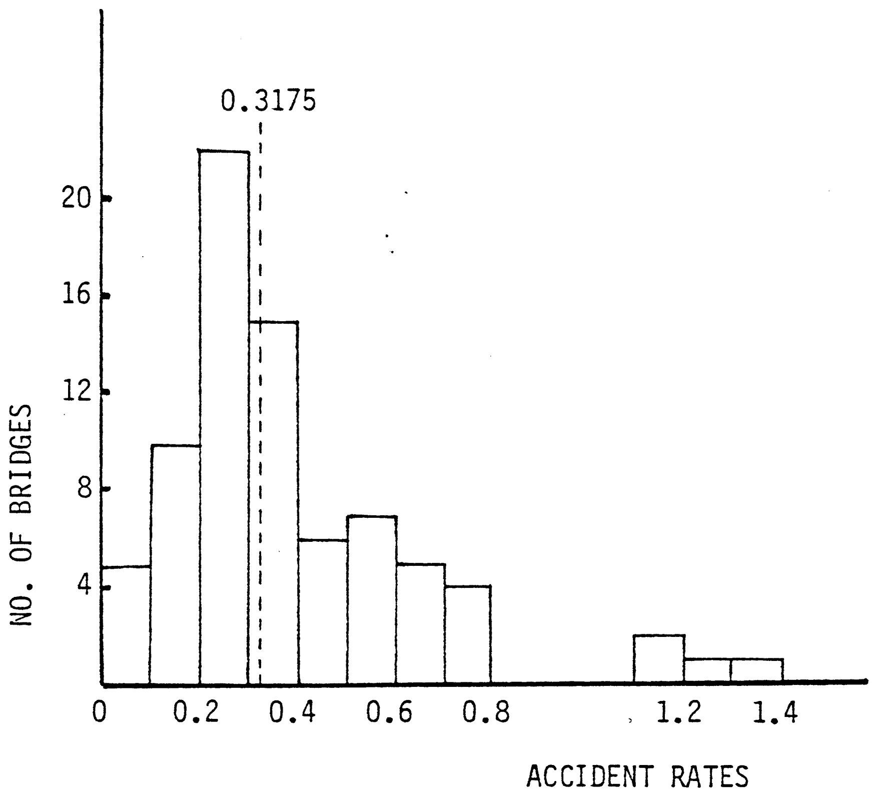

Fig. 4. Distribution of Accident Rate Data

Table 6. Coefficients Used with Discriminant Function Based on Accident Rates

Variable	Coefficient
F1	1.92
F2	0.07
F3	-0.17
F4	-0.50
F5	0.28
F6	0.0004
F7	0.02
F8	0.02
F9	-0.13
F10	0.49
F11	0.26
F12	-0.48

Eq.(6) is quite different from Eq.(5). Not only do negative signs appear in some of the factors but most of the coefficients reduce. Also, one might expect that there would be a large coefficient on F_1, F_2, and F_3 of the bridges studied. It is apparent in Eq.(6) that although F_1 is significant, F_2 and F_3 are only slightly significant. It is worth stressing the point that the evaluation of the ABSI based on Eq.(6) would cause a problem later in the determination of the Priority Index, since the value of ABSI after some recommended treatments would be higher than that of ABSI before treatments. However, Eq.(6) may be used as a reference for evaluating ABSI before treatment, although some drawbacks exist in using it to define the Priority Index.

Multiple Linear Regression Analysis

An additional investigation is conducted to examine the effects of the selected 12 factors on accident rates at the 78 bridges. For this study, a simple linear multiple regression analysis is performed to determine which of the 12 factors, if any, are related to accident rates. The basic equation of linear multiple regression analysis can be expressed as (4)

$$\widehat{AR}_i = \alpha_0 + \alpha_1 F_{i1} + \ldots\ldots + \alpha_{12} F_{i12} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (7)$$

where $\widehat{AR}$ = accident rate = No. of Accidents/Yr./1000 ADT,

$\alpha_0, \alpha_1, \ldots\ldots, \alpha_{12}$ = regression coefficients,

$F_1, F_2, \ldots\ldots, F_{12}$ = defined on preceeding pages, and

$i = 1,2,3,\ldots\ldots,78$.

It is desirable to observe the significance of each factor here. The results of analysis by a subprogram of the SAS System are summarized in Table 7. The values given in the Table 7 in which PR>|T| indicates the probability that the variable should not be in the model. Thus, when a very small value (<0.05) appears, it shows that the independent variable significantly contributes to the accident rate.

The most significant findings from the results are summarized as follows:

1. Only F_1 (bridge width) can be termed a strong indicator on accident rates with linear multiple regression analysis.
2. The selected 12 factors have only a weak correlation with accident rates since the coefficient of determination, R^2 is a small value of 0.26.

Stepwise Regression Analysis

A better analysis of the relationship between the factors and accident rates is to employ the "STEPWISE" procedure in the SAS System. The purpose of this procedure is to extract the more highly significant variables to be used in the model. Sometimes several variables in the model at the same time may interact with one another and cause the really significant variables to be "concealed". Once some of the variables are deleted, the really significant variables are gradually revealed.

The "STEPWISE" procedure begins by finding the single variable that produces the highest correlation (R^2) with accident rates. Then the "STEPWISE" procedure calculates the F-statistic reflecting this variable's contribution to the model if it is to be included. If it is not

Table 7. Results from Linear Multiple Regression Analysis

Variable	Coefficient	PR>|T|	R^2
F1	-0.256	0.0007	0.2589
F2	0.016	0.5735	
F3	0.002	0.9352	
F4	0.041	0.4696	
F5	-0.023	0.3013	
F6	-0.034	0.1183	
F7	-0.001	0.9630	
F8	-0.024	0.6307	
F9	-0.002	0.9544	
F10	-0.009	0.7424	
F11	-0.003	0.9222	
F12	0.016	0.7169	
Intercept	1.715	0.0034	

significant, the "STEPWISE" procedure stops at this stage. Otherwise, the "STEPWISE" procedure adds the variable that has the largest F-statistic to the model. After a variable is added, however, the "STEPWISE" procedure looks at all of the rest of the variables already included in the model and deletes any variable that does not produce an F-statistic which is significant at the 0.05 level (which is specified in this study). Only after this check is made and the necessary deletions accomplished can another variable be added to the model (6).

The results of the "STEPWISE" analysis are shown in Table 8 in which F_1 is a strongly significant indicator of the accident rate. These results also imply that among the selected 12 factors, F_1 and F_6 are the only ones that are significantly correlated to the accident rates. The linear regression model that contains F_1 and F_6 has a coefficient of determination (R^2) of 0.226.

Table 8. Results of STEPWISE Procedure.

Variable	Coefficient	F	PROB>F
Intercept	1.6485		
F1	-0.2322	15.18	0.0002
F6	-0.0369	3.60	0.0615
$R^2 = 0.2256$			

CHAPTER IV

APPLICATION FROM ANALYSIS

There are two applications on the BSI developed in this study: (a) identify the potentially hazardous bridge, and (b) estimate the priority index. The main feature of the discriminant analysis is to assign bridges to either the safe or hazardous group on the basis of data that are related to the group. The estimation of the priority index follows the model presented by D. L. Ivey, et.al. The following section will illustrate these two applications.

Identify the Boundary of the Potentially Hazardous Bridge

While the new BSI has been estabilished, the next objective in this study is the determination of the boundary score which will be used to classify a bridge into the safe or hazardous group. In accordance with the theory of linear discriminant analysis, the way to determine the boundary score is a half distance between the mean values of the group "1" (safe) and the mean values of the group "0" (hazardous), namely (7),

$$\frac{1}{2}\left(\overline{MBSI_1} + \overline{MBSI_0}\right) \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (8)$$

where $\overline{MBSI_1}$ = the mean of MBSI for the assumed safe bridges, and

$\overline{MBSI_0}$ = the mean of MBSI for the assumed hazardous bridges.

Table 9 shows the mean of each factor in Group "1" and Group "0", respectively. The mean value of MBSI for the safe bridge, which is obtained by substituting the mean value of each factor shown in Table 9

Table 9. The Mean of Group "1" and Group "0" for Each Variable.

Variable	Group "1" (Safe)	Group "0" (Hazardous)
F1	4.894	4.742
F2	3.219	2.467
F3	2.063	1.151
F4	5.000	4.658
F5	4.625	3.474
F6	4.475	3.342
F7	2.150	1.579
F8	4.575	4.342
F9	3.350	2.842
F10	3.725	2.579
F11	2.200	1.316
F12	2.075	2.368

into Eq.(5), is 47.93. The mean BSI for a hazardous bridge is 37.78. The midpoint then is $\frac{1}{2}(47.93 + 37.78) \approx 42.85$. Thus the classification rule is: a bridge is more like a safe bridge if its value of MBSI is above 42.85 and more like the potentially hazardous bridge if MBSI is below 42.85. An engineer may use this boundary score to assign a bridge into the group it most resembles and then propose an appropriate corrective treatment. In addition, if the MBSI of a bridge has an unsafe score (<42.85) it indicates that treatment is necessary, and in some cases, urgent. Also, the lower an MBSI score is below the boundary value, the higher its ranking is likely to be in determining priorities for corrective treatment.

Estimation of Priority Index

One of the major features of developing a Bridge Safety Index is the determination of the priority ranking for the corrective treatment of a bridge. Basically, a model of the Priority Index here is following the one proposed by D. L. Ivey, et.al. (1). Table 10 presents a Priority Index calculation for some of the study bridges selected from seven districts in the State of Texas. All ratings after treatments are developed from recommendations by each district and from the available slides made by the Texas Transportation Institute in the field. One of the 78 study bridges is evaluated in detail below.

Bridge Site - Tarrant 220, 2C; District 2.

Before treatments, MBSI is a value of 45.05 (see also Table 4). According to recommendations of the district, the following corrective measures should be taken:

Table 10. Priority Index for Selected Bridge Sites

Bridge Site	BSI_a	BSI_b	ADT	COST	PI
2C--Tarrant 220	52.17	45.05	4,300	500	61.20
2D--Wise 249	57.58	51.60	3,200	81,950	0.23
2E--Erath 73	53.37	46.17	7,300	24,550	2.14
2F--Erath 73	49.91	41.51	900	14,450	0.52
2G--Hood 112	54.84	48.86	7,600	49,450	0.92
2H--Erath 73	54.87	50.10	900	44,500	0.10
9A--Bell 14	44.41	40.66	3,920	10,400	2.80
9F--Bell 14	46.37	36.60	2,650	21,500	1.20
9G--Bell 14	52.77	37.61	2,130	15,150	2.13
12A--Brazoria 20	53.16	46.49	7,140	16,690	2.86
12G--Harris 102	40.78	46.49	17,200	101,500	1.73
12I--Brazoria 20	49.27	40.30	6,670	83,840	0.71
12J--Brazoria 20	46.89	43.03	6,990	19,750	3.86
12K--Harris 102	58.34	49.24	14,780	20,895	6.44
12L--Montgmry 170	54.02	47.89	6,520	56,255	0.71
13A--Calhoun 29	54.67	51.04	3,300	9,100	1.32
13B--Colorado 45	46.08	34.85	6,700	6,200	12.14
13F--Dewitt 62	47.46	41.40	3,700	1,100	20.38
13D--Fayette 76	45.29	36.32	7,800	6,500	10.77
13E--Gonzales 90	53.42	39.87	5,600	22,100	3.43

Table 10. (Continued)

Bridge Site	BSI_a	BSI_b	ADT	COST	PI
13C--Dewitt 62	45.31	41.03	3,700	1,100	14.40
14C--Llano 150	43.58	36.39	7,500	4,950	10.91
14H--Wmson 246	57.26	49.50	1,800	33,000	0.42
18B--Denton 61	51.52	41.03	7,800	100,000	0.82
18C--Kaufman 130	50.96	43.54	3,700	112,000	0.26
18D-Navarro 175	63.40	51.77	2,800	286,000	0.11
20B--Hardin 101	54.26	45.32	7,470	39,000	1.71
20F--Jasper 122	54.26	45.32	7,470	113,000	0.59
20H--Liberty 146	54.94	46.53	1,400	31,000	0.38
20I--Hardin 101	51.76	45.78	7,000	21,000	2.00

1. bring and maintain paint markings to high level,
2. place diagonal markings on the right shoulder of both approaches, and
3. place edge lines on approaches and across the bridge.

On the basis of above recommendations and rating factor criteria, only F_{11} would be changed and has a value of 5. After substituting all rating factors into Eq.(5), a value of MBSI with 52.17 is obtained for after treatments and the Priority Index using the calculation shown in Eq.(2) is 61.2.

CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

A successful method using discriminant analysis to evaluate a BSI has been presented in Chapter III. The discriminant function (BSI) based on the modified Bridge Safety Index score criterion has also been shown in Eq.(5). It should be noted that the new Bridge Safety Index was obtained from discriminant analysis by assuming that a linear combination of the variables can properly distinquish between safe and hazardous bridges. This assumption is correct only under the following conditions:

1. the variance and covariances should be the same in both groups, and
2. the variables are multivariate normal.

If the above conditions are not met, non-parametric or non-linear discriminant analysis is more appropriate. In addition, the data is classified by an "a priori" score criterion into two groups. This inevitably leads to a misclassification of the data. The selected factors used in analysis have been assumed to be representative of bridge safety, and the score developed from these factors is assumed to be meaningful. Despite the restrictions mentioned above, the prediction results obtained from discriminant analysis are encouraging. It is also believed that this approach is a step further in the rationalization of a Bridge Safety Index for narrow bridges.

A promising evaluation of the Bridge Safety Index from the point of view of accident rates has been shown in Eq.(6). However, the factors that are used in such an ABSI should be those that can be shown to contribute significantly to accident rates. As mentioned in Chapter IV, only F_1 and F_6 were found to be involved in accident rates through the "STEPWISE" regression analysis. However, the safety of narrow bridges is known to involve other factors than F_1 and F_6 (1). In addition, it should be pointed out here that in using multiple regression or stepwise regression analysis it is important to use large samples. Accordingly, the sample size in multiple regression or stepwise problem should be 100 or at least 20 times the number of variables (4). This is also one of the reasons that Eq.(6), which is based on an accident rate criterion used with discriminant analysis, cannot be recommended for use as an accident-related Bridge Safety Index, at the present time. It is the conviction of the author that if a sufficient quantity of data were available to allow such an analysis to be made then the resulting ABSI would be a superior method of rating bridge safety.

Recommendations

The following recommendations are made concerning further steps to develop an improved Bridge Safety Index for narrow bridges.

1. It is necessary to collect more bridge site data for analysis, especially at narrow bridge sites, where the bridge width is less than 24 feet. The width of most of the 78 bridges used in this study are greater than 24 feet. It is believed that an evaluation of BSI would be more reasonable by discriminant analysis based on the same geometric and structural conditions of the bridge site.

2. It is desirable to collect more comprehensive accident data for each bridge site. Thus, on the basis of accident data the appropriate factors contributed to bridge safety can be made by statistical techniques. With these kinds of data being available, the Bridge Safety Index could be related not only to accident rates, but to their severity. Including severity of accident as a criterion for classifying bridges as safe or hazardous will probably make bridge structural and geometric conditions more important in determining an ABSI. Finally, the method of linear or non-linear discriminant analysis could be performed based on accident rates.

REFERENCES

1. Ivey, D. L., Olson, R.M., Walton, N.E., Weaver, G. D., and Furr, L. Whitehurst, "Safety at Narrow Bridge Sites", NCRP Report 203, Transportation Research Board, 1979.

2. Turner, D. S., "A Technique for Selecting Bridge Safety Treatments", Ph.D. Dissertation, Texas A&M University, 1980.

3. Newton, T. M., "A Method of Field Evaluation of Narrow Bridges for Priority Indexing", Research Report No. 233-1, Texas Transportation Institute, 1979.

4. Lindeman, R. H., Merenda, P. F., and Gold, R. Z., Introduction to Bivariate and Multivariate Analysis, Scott, Foresman and Company, 1980.

5. Kendall, M. G., Multivariate Analysis, Macmillan Publishing Company, Incorporated, New York, 2nd Ed., 1980.

6. SAS Institute, SAS User's Guide, SAS Institute, North Carolina, 1979.

7. Lachenbruch, P. A., Discriminant Analysis, Hafner Press, A Division of Macmillan Publishing Company, Incorporated, New York, 1974.

APPENDIX I

Original BSI for Study Bridges

Bridge Site	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	BSI
2C--Tarrant 220	20	20	20	5	5	1	1	4	3	3	82
2D--Wise 249	20	15	10	5	5	5	1	5	2	5	73
2E--Erath 73	20	20	5	5	5	2	1	4	4	2	68
2F--Erath 73	18	10	0	4	4	3	1	5	3	4	50
2G--Hood 112	20	20	10	5	5	5	1	4	2	2	74
2H--Erath 73	18	10	15	5	5	5	1	5	4	4	72
9A--Bell 14	20	5	5	5	5	1	2	4	3	4	54
9F--Bell 14	20	5	10	5	5	1	3	5	2	3	59
9G--Bell 14	20	15	0	3	1	5	1	2	1	4	52
10D--Henderson 108	20	10	5	5	5	5	2	4	2	2	60
10F--Anderson 001	17	5	0	5	5	2	5	5	4	4	52
10G-- Gregg 93	20	5	5	5	5	5	5	4	5	4	63
10H Van Zandt 234	10	10	0	5	3	1	5	5	4	4	47
10I--Anderson 001	20	15	10	5	5	5	1	4	1	1	67
10C--Henderson 108	20	10	5	5	5	5	2	4	2	2	60
11C--Trinity 228	20	10	5	5	4	5	1	4	3	3	60
11D--Trinity 228	20	10	5	5	5	5	1	4	3	3	61
11E--Houston 114	20	15	5	5	5	5	5	5	5	5	75
11F--San Aug 203	20	10	5	5	5	5	2	5	4	4	65
12A--Brazoria 20	20	15	5	5	1	5	1	4	4	4	64
12G--Harris 102	20	10	0	5	5	1	1	2	2	1	47
12I--Brazoria 20	20	15	5	5	5	1	1	4	4	3	63
12J--Brazoria 20	20	5	0	5	5	5	5	4	3	3	55

Bridge Site	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	BSI
12K--Harris 102	20	5	0	5	5	5	5	4	4	4	57
12L--Montgmry 170	20	10	5	5	5	5	5	4	2	2	63
13A--Calhoun 29	20	10	5	5	5	5	2	5	3	5	65
13B--Colordo 45	20	10	0	5	1	4	1	4	2	2	49
13F--Dewitt 62	20	10	20	5	5	5	1	4	3	1	74
13D-Fayette 76	20	10	5	5	3	4	1	4	3	2	57
13E--Gonzales 90	20	10	10	5	5	5	1	4	4	1	65
13C--Dewitt 62	20	10	15	5	4	5	1	4	3	1	68
14A--Bastrop 11	20	5	5	5	2	3	1	4	5	2	52
14C--Llano 150	20	10	5	5	5	3	1	5	3	1	58
14E--Bastrop 11	18	5	5	5	5	3	5	5	5	5	63
14F--Hays 106	20	10	5	1	1	1	5	5	3	1	52
14D--Wmson 246	20	20	10	5	5	4	1	5	4	5	79
14H--Wmson 246	20	20	10	5	5	4	1	5	4	4	78
14I--Wmson 246	20	20	20	5	2	5	1	4	4	3	84
16D--Refugio 196	20	10	15	5	3	3	3	4	2	4	69
16E--Refugio 196	20	10	20	5	5	5	3	4	2	4	78
16F--Sanpatricio 205	15	10	15	5	5	5	1	5	3	4	68
16G--Sanpatricio 205	15	10	15	5	5	5	1	5	3	4	68
18B--Denton 61	20	10	15	5	5	5	1	4	2	2	69
18C--Kaufman 130	20	15	10	5	1	4	1	4	2	3	65
18D--Wavarro 175	20	20	0	5	5	5	1	5	5	5	71
20B--Hardin 101	20	10	5	5	5	5	2	4	2	4	62
20F--Jasper 122	20	10	5	5	5	5	2	4	2	4	62
20H--Liberty 146	15	20	0	5	5	5	1	5	2	4	62

Bridge Site	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	BSI
20I--Hardin 101	20	15	5	5	5	5	1	4	3	3	66
3B--Wichita 243	18	5	0	5	4	5	1	5	4	3	50
3C--Wilbarger 244	18	5	10	1	3	4	1	5	2	3	56
3D--Wilberger 244	18	5	0	5	3	5	1	5	2	3	48
3E--Wilberger 244	18	5	0	5	5	5	1	5	2	3	49
3F--Young 252	18	0	0	4	5	3	1	5	2	4	42
3G--Young 252	15	10	0	5	3	2	1	5	2	4	47
3H--Montaque 169	18	5	0	5	5	2	1	5	3	4	48
4A--Hartley 104	20	15	15	5	5	5	1	5	2	3	76
4B--Hemphill 107	20	20	10	5	1	5	1	5	3	4	74
4D--Oldham 180	20	10	10	5	1	2	1	5	2	4	60
4E--Oldham 180	20	15	5	5	4	3	1	5	2	4	64
4F--Randall 191	20	20	0	5	3	2	1	4	4	2	61
7A--Coke 41	20	10	10	5	5	4	2	5	3	4	68
7G--Tom Green 226	17	5	0	2	1	5	5	5	3	2	45
7H--Tom Green 226	20	15	10	4	3	5	1	3	4	2	67
7I--Tom Green 226	20	10	5	5	1	2	2	4	4	2	55
21A--Kenedy 66	20	10	5	5	5	4	4	4	2	4	63
21B--Duval 67	20	10	20	5	5	5	5	5	4	5	84
21D--Hidalgo 109	20	15	0	5	3	5	1	5	4	3	61
21G--Webb 240	20	10	5	4	1	2	1	4	3	2	52
21H--Zapata 253	20	15	10	5	5	4	1	5	3	4	72
21I--Zapata 253	20	15	10	5	5	4	1	4	3	2	69
22A--Kinney 136	20	5	10	5	5	4	3	5	4	3	64
22B--Kinney 136	20	10	5	5	5	3	3	5	4	5	65

Bridge Site	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	BSI
22C--Maverick 159	20	10	0	5	5	5	3	5	4	3	60
22D--Uvalde 232	20	15	0	5	5	4	1	5	5	4	64
22E--Val Verde 233	20	20	5	5	5	2	1	5	4	1	68
22F--Val Verde 233	20	15	5	5	1	4	1	5	4	2	62
22H--Zavala 254	20	15	0	5	5	5	1	5	4	4	64

APPENDIX II

Summary of Recommendations for Corrective Treatments from Districts of Texas

1. Bring and maintain paint markings to high level
2. Place edge lines on approaches and across the bridge
3. Place diagonal markings on right shoulder of both approaches
4. Mark for no passing zones
5. Install object marking
6. Install narrow bridge sign
7. Install reflective markings on rails
8. Block out approach rails to face appron curb
9. Tie approach rails to bridgerails
10. Bring approach rails up to standard
11. Block out bridge rail
12. Place W-section on bridge rails
13. Remove large trees (or historical marker)
14. Use herbicide (Vegetation control)
15. Relocate field road
16. Clean R.O.W. under bridge
17. Install adequate approach rail to deny acess near bridge

APPENDIX III

Computer Listing of Discriminant Analysis Based on MBSI Score

```
1                                   S T A T I S T I C A L   A N A L Y S I S   S Y S T E M     1:00 THURSDAY, NOVEMBER 11, 1982

NOTE: THE JOB SASAUTO HAS BEEN RUN UNDER RELEASE 79.6 OF SAS AT TEXAS A&M UNIVERSITY (00562).
           $JOB SASJOB/W188,T=02,L=002000


2          DATA BRIDGE ;
3          TITLE MODIFIED BRIDGE SAFETY INDEX;
4          INPUT F1 17-20 F2 22-25 F3 27-30 F4 32 F5 34 F6 36 F7 38
5                F8 40 F9 42 F10 44 F11 46 F12 48 GROUP 52;
6          CARDS;

NOTE: DATA SET WORK.BRIDGE HAS 78 OBSERVATIONS AND 13 VARIABLES. 114 OBS/TRK.
NOTE: THE DATA STATEMENT USED 0.13 SECONDS AND 124K.

85         PROC DISCRIM LIST POOL=YES;
86         CLASS GROUP;
87         PRIORS PROP;

NOTE: THE PROCEDURE DISCRIM USED 0.43 SECONDS AND 164K AND PRINTED PAGES 1 TO 7.

NOTE: SAS USED 164K MEMORY.

NOTE: SAS INSTITUTE INC.
      SAS CIRCLE
      BOX 8000
      CARY, N.C. 27511-8000

NOTE: THE JOB USED 0.63 SECONDS AND PRINTED 8 PAGES.
```

DISCRIMINANT ANALYSIS

GROUP	FREQUENCY	PRIOR PROBABILITY
0	38	0.48717949
1	40	0.51282051
TOTAL	78	1.00000000

DISCRIMINANT ANALYSIS POOLED COVARIANCE MATRIX INFORMATION

COVARIANCE MATRIX RANK	NATURAL LOG OF DETERMINANT OF THE COVARIANCE MATRIX
12	-3.25493480

DISCRIMINANT ANALYSIS PAIRWISE SQUARED GENERALIZED DISTANCES BETWEEN GROUPS

$$D^2(I|J) = (\bar{X}_I - \bar{X}_J)' \, COV^{-1} \, (\bar{X}_I - \bar{X}_J) - 2 \, LN \, PRIOR_J$$

GENERALIZED SQUARED DISTANCE TO GROUP

FROM GROUP	0	1
0	1.43824533	11.53575863
1	11.63834522	1.33565875

MODIFIED BRIDGE SAFETY INDEX 1:00 THURSDAY, NOVEMBER 11, 1982 4

DISCRIMINANT ANALYSIS LINEARIZED DISCRIMINANT FUNCTION

CONSTANT = $-.5 \bar{X}_J' \, COV^{-1} \, \bar{X}_J + LN \, PRIOR_J$ COEFFICIENT VECTOR = $COV^{-1} \, \bar{X}_J$

	GROUP	
	0	1
CONSTANT	-245.98342905	-288.87494499
F1	41.80332766	43.28721813
F2	11.09216084	13.28483515
F3	0.88196800	1.84763066
F4	22.10728199	22.57363355
F5	-0.40832845	0.52633190
F6	4.07708064	5.40999449
F7	11.38169409	12.81339283
F8	19.67665881	19.91121778
F9	-0.75423765	0.14659255
F10	2.00822379	3.75947539
F11	2.75862282	4.54146706
F12	16.32158789	17.04335117

DISCRIMINANT ANALYSIS CLASSIFICATION RESULTS FOR CALIBRATION DATA: WORK.BRIDGE

GENERALIZED SQUARED DISTANCE FUNCTION:

$$D_J^2(X) = (X-\overline{X}_J)' \; COV^{-1} \; (X-\overline{X}_J) - 2 \; LN \; PRIOR_J$$

POSTERIOR PROBABILITY OF MEMBERSHIP IN EACH GROUP:

$$PR(J|X) = EXP(-.5 \; D_J^2(X)) \; / \; SUM_K \; EXP(-.5 \; D_K^2(X))$$

POSTERIOR PROBABILITY OF MEMBERSHIP IN GROUP:

OBS	FROM GROUP	CLASSIFIED INTO GROUP	0	1
1	1	1	0.0988	0.9012
2	1	1	0.0002	0.9998
3	1	1	0.0336	0.9664
4	0	0	0.7865	0.2135
5	1	1	0.0024	0.9976
6	1	1	0.0007	0.9993
7	0	0	0.8969	0.1031
8	0	0	0.9980	0.0020
9	0	0	0.9946	0.0054
10	0	0	0.9417	0.0583
11	0	0	0.9725	0.0275
12	1	1	0.0002	0.9998
13	0	0	0.9937	0.0063
14	0	0	0.9487	0.0513
15	0	0	0.9417	0.0583
16	0	1 *	0.4448	0.5552
17	1	1	0.0000	1.0000
18	1	1	0.1155	0.8845
19	1	1	0.0251	0.9749
20	0	0	1.0000	0.0000
21	0	0	0.9262	0.0738
22	1	1	0.4458	0.5542
23	1	1	0.0016	0.9984
24	1	1	0.0062	0.9938
25	1	1	0.0003	0.9997
26	0	0	0.9997	0.0003
27	1	0 *	0.8088	0.1912
28	0	0	0.9985	0.0015
29	0	0	0.9505	0.0495
30	0	0	0.8583	0.1417
31	0	0	0.9615	0.0385
32	0	0	0.9999	0.0001
33	0	0	0.9984	0.0016
34	1	1	0.0134	0.9866
35	0	0	0.9999	0.0001
36	1	1	0.0002	0.9998
37	1	1	0.0013	0.9987
38	1	1	0.0035	0.9965
39	1	1	0.0267	0.9733
40	1	1	0.0000	1.0000
41	1	1	0.0296	0.9704
42	1	1	0.0296	0.9704
43	0	0	0.8580	0.1420
44	0	1 *	0.3314	0.6686
45	1	1	0.0001	0.9999

DISCRIMINANT ANALYSIS CLASSIFICATION SUMMARY FOR CALIBRATION DATA: WORK.BRIDGE

GENERALIZED SQUARED DISTANCE FUNCTION:

$$D_J^2(X) = (X-\overline{X}_J)' \; COV^{-1} \; (X-\overline{X}_J) - 2 \; LN \; PRIOR_J$$

POSTERIOR PROBABILITY OF MEMBERSHIP IN EACH GROUP:

$$PR(J|X) = EXP(-.5 \; D_J^2(X)) \; / \; \underset{K}{SUM} \; EXP(-.5 \; D_K^2(X))$$

NUMBER OF OBSERVATIONS AND PERCENTS CLASSIFIED INTO GROUP:

FROM GROUP	0	1	TOTAL
0	36	2	38
	94.74	5.26	100.00
1	1	39	40
	2.50	97.50	100.00
TOTAL	37	41	78
PERCENT	47.44	52.56	100.00
PRIORS	0.4872	0.5128	

APPENDIX IV

Summary of Accident Data

(period: 1974-1979)

Bridge Site	Accidents (No.) by Type								No. of people	
	Hit Side of Bridge	Hit Bridge End	Hit Guardrail	Hit Fixed Object	Hit Other Object	Hit Animal	Collision	Total	Killed	Injured
2C Tarrant 220	1			1			1	3	0	2
2D Wise 249	1	1					3	5	2	2
2E Erath 73		1	2				1	4	0	2
2F Erath 73	3	2		1				6	0	4
2G Hood 112	7	1					2	10	0	3
2H Erath 73	1					1	1	3	1	0
3B Wichita 243	2	1		1			1	5	1	4
3c Wilbarger 244	9					1		10	0	1
3D Wilbarger 244	2	1						3	0	2

Bridge Site	Accidents (No.) by Type								No. of people	
	Hit Side of Bridge	Hit Bridge End	Hit Guardrail	Hit Fixed Object	Hit Other Object	Hit Animal	Collision	Total	Killed	Injured
3E Wilbarger 244	1							1	0	0
3F Young 252	4	1					1	6	0	0
3G Young 252	1						2	3	0	3
3H Montague 169								0	0	0
4A Hartley 104	2	1						3	0	0
4B Hemphill 107	5						5	10	0	2
4D Oldham 180	1	1						2	2	1
4E Oldham 180	3							3	0	1
4F Randall 191	4	2			1		3	10	0	12

Bridge Site	Accidents (No.) by Type								No. of People	
	Hit Side of Bridge	Hit Bridge End	Hit Fixed Object	Hit Other Object	Hit Animal	Overturned	Collision	Total	Killed	Injured
7A Coke 41								0	0	0
7G Tom Green 226	3						1	4	0	4
7H Tom Green 226	6			1			7	14	0	7
7I Tom Green 226	2	1					6	9	0	5
9A Bell 14	2	2					3	7	0	0
9F Bell 14		1			1		5	7	1	10
9G Bell 14	6					1		7	0	0
10D Henderson 108	7	1	1			1	8	18	2	16
10F Anderson 1	1	1					4	6	0	2

Bridge Site	Accidents (No.) by Type								No. of People	
	Hit Side of Bridge	Hit Bridge End	Hit Fixed Object	Hit Other Object	Hit Animal	Overturned	Collision	Total	Killed	Injured
10G Gregg 93	2			1				3	0	1
10H Van Zandt 234	2	1				1	1	5	0	3
10I Anderson 1	3						6	9	0	2
10C Henderson 108	4			1		1	3	9	0	2
11C Trinity 228	4						3	7	0	5
11D Trinity 228	3	2					10	15	2	13
11E Houston 114	1	1		1				3	1	3
11F San Aug 203	1	2						3	0	0
12A Brazoria 20	1						4	5	0	4

Bridge Site	Accidents (No.) by Type								No. of People	
	Hit Side of Bridge	Hit Bridge End	Hit Guardrail	Hit Fixed Object	Hit Animal	Non-Collision	Collision	Total	Killed	Injured
12G Harris 102	4	1	1	7		1	51	65	2	37
12I Brazoria 20	4	1					44	49	0	12
12J Brazoria 20	7	2	1				1	11	0	2
12K Harris 102	4	1					1	6	2	6
12L Montgmry 170	3	2			1		5	11	0	5
13A Calhoun 29	5							5	1	2
13B Colorado 45	3						16	19	0	7
13F Dewitt 62	4						4	8	0	6
13D Fayette 76	2	1	2		1	1	25	32	0	4

Bridge Site	Accidents (No.) by Type								No. of People	
	Hit Side of Bridge	Hit Bridge End	Hit Fixed Object	Hit Other Object	Hit Animal	Overturned	Collision	Total	Killed	Injured
13E Gonzales 90	5						6	11	0	8
13C Dewitt 62	1						4	5	1	1
14A Bastrop 11	4	1					12	17	0	9
14C Llano 150	4	1	1	1		1	8	16	0	11
14E Bastrop 11	2							2	0	1
14F Hays 106	3						1	4	0	1
14D Wmson 246	2						1	3	0	3
14H Wmson 246	2		1					3	0	0
14I Wmson 246	3	2					1	6	0	0

Bridge Site	Accidents (No.) by Type								No. of People	
	Hit Side of Bridge	Hit Bridge End	Overturned	Hit Other Object	Hit Animal	Non-Collision	Collision	Total	Killed	Injured
16D Refugio 196	2		1				1	4	0	0
16E Refugio 196	20	2		1		1	1	25	0	13
16F Sanpatricio 205	2						3	5	0	0
16G Sanpatricio 205	2		1				4	7	0	1
18B Denton 61	11						8	19	2	11
18C Kaufman 130	6	4					2	12	0	5
18D Navarro 175	3				2			5	0	0

Bridge Site	Accidents (No.) by Type								No. of People	
	Hit Side of Bridge	Hit Bridge End	Hit Animal	Hit Other Object	Hit Pedestrian or Byclist	Non-Collision	Collision	Total	Killed	Injured
20B Hardin 101	1						1	2	0	2
20F Tasper 122	4			1			7	12	1	1
20H Liberty 146	1						3	4	0	1
20I Hardin 101	1				1	1		3	0	1
21A Kendey 66	6	1						7	3	10
21D Hidalgo 109	1				1		1	3	1	0
21H Zapata 253	5	1	1				1	8	1	8
21I Zapata 253	2	1	1				2	6	3	3

Bridge Site	Accidents (No.) by Type								No. of People	
	Hit Side of Bridge	Hit Bridge End	Hit Guardrail	Hit Fixed Object	Hit Other Object	Non-Collision	Collision	Total	Killed	Injured
21B Duval 67	2		1					3	0	2
21G Webb 240	4	1	1	1				7	1	8
22A Kinney 136	1		1					2	0	3
22B Kinney 136	2							2	0	1
22C maverick 159	2							2	0	0
22D Uvalde 232	1	1						2	0	1
22E Val Verde 233	1						2	3	0	0
22F Val Verde 233	4				3	2	1	10	0	8
22H Zavala 254							2	2	0	0

APPENDIX V

Computer Listing of Discriminant Analysis

Based on Accident Rate

ACCIDENT-RELATED BRIDGE SAFETY INDEX 2:04 FRIDAY, NOVEMBER 12, 1982

DISCRIMINANT ANALYSIS

GROUP	FREQUENCY	PRIOR PROBABILITY
0	38	0.48717949
1	40	0.51282051
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TOTAL	78	1.00000000

DISCRIMINANT ANALYSIS POOLED COVARIANCE MATRIX INFORMATION

COVARIANCE MATRIX RANK	NATURAL LOG OF DETERMINANT OF THE COVARIANCE MATRIX
12	-2.22818600

DISCRIMINANT ANALYSIS PAIRWISE SQUARED GENERALIZED DISTANCES BETWEEN GROUPS

$$D^2(I|J) = (\bar{X}_I - \bar{X}_J)' \ \mathrm{COV}^{-1} \ (\bar{X}_I - \bar{X}_J) - 2 \ \mathrm{LN} \ \mathrm{PRIOR}_J$$

GENERALIZED SQUARED DISTANCE TO GROUP

FROM GROUP	0	1
0	1.43824533	2.48588516
1	2.58847175	1.33565875

DISCRIMINANT ANALYSIS LINEARIZED DISCRIMINANT FUNCTION

$\text{CONSTANT} = -.5\ \bar{X}_J'\ \text{COV}^{-1}\ \bar{X}_J + \text{LN PRIOR}_J$ $\text{COEFFICIENT VECTOR} = \text{COV}^{-1}\ \bar{X}_J$

	GROUP	
	0	1
CONSTANT	-203.96724028	-212.47095165
F1	40.30510097	42.22545066
F2	5.59869260	5.66655717
F3	-1.77090991	-1.93824815
F4	20.32654528	19.82382671
F5	-2.45343195	-2.17404010
F6	0.68928987	0.68971644
F7	7.76071700	7.77628356
F8	19.10518312	19.12610924
F9	-3.19675697	-3.32562407
F10	-1.86013014	-1.36745761
F11	-1.46707128	-1.20836109
F12	13.92271668	13.44628647

DISCRIMINANT ANALYSIS CLASSIFICATION RESULTS FOR CALIBRATION DATA: WORK.BRIDGE

GENERALIZED SQUARED DISTANCE FUNCTION:

$$D_J^2(X) = (X-\overline{X}_J)' \, COV^{-1} (X-\overline{X}_J) - 2 \, LN \, PRIOR_J$$

POSTERIOR PROBABILITY OF MEMBERSHIP IN EACH GROUP:

$$PR(J|X) = EXP(-.5 \, D_J^2(X)) \, / \, SUM_K \, EXP(-.5 \, D_K^2(X))$$

POSTERIOR PROBABILITY OF MEMBERSHIP IN GROUP:

OBS	FROM GROUP	CLASSIFIED INTO GROUP	0	1
1	1	0 *	0.5048	0.4952
2	1	1	0.1225	0.8775
3	1	1	0.4929	0.5071
4	0	1 *	0.3854	0.6146
5	1	1	0.3648	0.6352
6	0	0	0.6253	0.3747
7	1	1	0.2884	0.7116
8	0	1 *	0.4193	0.5807
9	0	1 *	0.2090	0.7910
10	0	1 *	0.4769	0.5231
11	0	0	0.9203	0.0797
12	1	1	0.2368	0.7632
13	0	0	0.9861	0.0139
14	0	0	0.6014	0.3986
15	1	1	0.4769	0.5231
16	0	1 *	0.3320	0.6680
17	0	1 *	0.2081	0.7919
18	1	1	0.2113	0.7887
19	1	1	0.4282	0.5718
20	0	0	0.6741	0.3259
21	0	0	0.5204	0.4796
22	1	1	0.3482	0.6518
23	1	1	0.1812	0.8188
24	1	1	0.3415	0.6585
25	1	1	0.0621	0.9379
26	0	0	0.7407	0.2593
27	0	0	0.7636	0.2364
28	0	0	0.6482	0.3518
29	0	0	0.7074	0.2926
30	1	0 *	0.7279	0.2721
31	1	1	0.3458	0.6542
32	0	0	0.8469	0.1531
33	0	1 *	0.4476	0.5524
34	0	1 *	0.2376	0.7624
35	1	0 *	0.5116	0.4884
36	1	1	0.2179	0.7821
37	1	1	0.3132	0.6868
38	1	0 *	0.7280	0.2720
39	1	1	0.3469	0.6531
40	0	1 *	0.2241	0.7759
41	0	0	0.8892	0.1108
42	0	0	0.8892	0.1108
43	0	0	0.5846	0.4154
44	0	0	0.6529	0.3471
45	1	1	0.2513	0.7487

DISCRIMINANT ANALYSIS CLASSIFICATION RESULTS FOR CALIBRATION DATA: WORK.BRIDGE

POSTERIOR PROBABILITY OF MEMBERSHIP IN GROUP:

OBS	FROM GROUP	CLASSIFIED INTO GROUP	0	1
46	1	1	0.2081	0.7919
47	1	1	0.2081	0.7919
48	0	0	0.6637	0.3363
49	1	1	0.3134	0.6866
50	0	0	0.9013	0.0987
51	0	0	0.8981	0.1019
52	1	0 *	0.7826	0.2174
53	1	0 *	0.6730	0.3270
54	0	0	0.6825	0.3175
55	0	0	0.8413	0.1587
56	1	0 *	0.5251	0.4749
57	1	1	0.4361	0.5639
58	0	0	0.5506	0.4494
59	1	0 *	0.5609	0.4391
60	1	1	0.2916	0.7084
61	0	0	0.5896	0.4104
62	1	1	0.1475	0.8525
63	0	0	0.7975	0.2025
64	1	1	0.4765	0.5235
65	0	0	0.6916	0.3084
66	1	1	0.2910	0.7090
67	0	1 *	0.3202	0.6798
68	0	1 *	0.3577	0.6423
69	1	0 *	0.6611	0.3389
70	0	1 *	0.1672	0.8328
71	1	1	0.4157	0.5843
72	1	1	0.3574	0.6426
73	1	1	0.1068	0.8932
74	1	1	0.2060	0.7940
75	1	1	0.2709	0.7291
76	0	0	0.5020	0.4980
77	0	0	0.6126	0.3874
78	1	1	0.2461	0.7539

* MISCLASSIFIED OBSERVATION

DISCRIMINANT ANALYSIS CLASSIFICATION SUMMARY FOR CALIBRATION DATA: WORK.BRIDGE

GENERALIZED SQUARED DISTANCE FUNCTION:

$$D_J^2(X) = (X-\bar{X}_J)' \; COV^{-1} \; (X-\bar{X}_J) - 2 \; LN \; PRIOR_J$$

POSTERIOR PROBABILITY OF MEMBERSHIP IN EACH GROUP:

$$PR(J|X) = EXP(-.5 \; D_J^2(X)) \; / \; \underset{K}{SUM} \; EXP(-.5 \; D_K^2(X))$$

NUMBER OF OBSERVATIONS AND PERCENTS CLASSIFIED INTO GROUP:

FROM GROUP	0	1	TOTAL
0	26	12	38
	68.42	31.58	100.00
1	9	31	40
	22.50	77.50	100.00
TOTAL	35	43	78
PERCENT	44.87	55.13	100.00
PRIORS	0.4872	0.5128	